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ATMOSAT / Development Plan for FY 76

Aerospace Corp.

T. F. Heinsheimer

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DEVELOPMENT PLAN FOR FY '76

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THE AEROSPACE CORPORATION
2350 El Segundo Blvd.
El Segundo, California 90009

Company Sponsored Research Grant No. 8192

FOREWORD

The work described in this report is supported by Aerospace Company Sponsored Research Grant No. 8192, in cooperation with the Service d'Aeronomie (CNRS-Paris, France) and the French Space Administration (CNES).

T. F. Heinsheimer
Director, ATMOSAT

ABSTRACT

The ATMOSAT program is aimed at the design, construction, and flight of a lighter than air vehicle capable of carrying a one-ton scientific payload in the stratosphere for a flight of one year. The FY'76 activities concentrate on accumulating information needed on the physics of flight of such a vehicle. A flight test program is being implemented, which will start with two long duration (nonrecoverable) stratospheric tests of small (3.5-meter diameter) ATMOSAT models; proceed to a series of recoverable low altitude tropospheric flights of an intermediate size (10 meters) vehicle; and end with a long duration stratospheric flight of that vehicle. The results of these flights, of the ground testing which will precede them, and of the computer modeling which will make use of the accumulated data should allow the design and flight of the first operational ATMOSAT in FY '77.

CONTENTS

I. BACKGROUND AND ORIGINS OF THE ATMOSAT PROGRAM

Aside from some applications of hot-air and dilatable neoprene balloons (the latter usually encountered in meteorological soundings), the majority of large balloon-borne scientific payloads have been carried by stratospheric "zero-pressure" balloons. These are polyethylene envelopes having volumes of up to several million cubic meters which expand during ascent with dilation of the lifting gas until the full volume of the balloon is inflated. As the balloon continues to rise above this point, excess gas is vented through an evacuation sleeve hanging below the balloon body. This gas loss decreases the net lift of the balloon until such an altitude is reached where the atmospheric density equals the total weight of the balloon ensemble divided by the volume of the lifting gas. The net lift is then zero, and the balloon floats at that altitude until equilibrium is disturbed. Perturbations of equilibrium are most often of thermal origin. At sunset, the lifting gas cools and contracts, reducing the effective volume of the balloon. Unless this effect is counteracted by the dropping of ballast, the balloon will lose altitude, often to the extent of descending to sea level. Though a ballasting arrangement can extend the lifetime of such balloons, it requires an ever increasing portion of the payload weight as the required lifetime is extended; for flights of over a week, the method results in there being nearly no payload at all.

The superpressure balloon (as shown in Figure 1) operates on the same principle during ascent until such time as the envelope is completely inflated. As the balloon continues to rise, the gas, having no orifice through which to escape, remains in the balloon creating a differential pressure across the envelope. Continued ascent at constant volume is accompanied by loss of net lift owing to the decreasing atmospheric density, until finally the lift becomes zero and the balloon floats stably at its ceiling altitude. <u>The overpressure now acts as a reserve of lift which prevents the balloon from losing stability</u> because of perturbing forces. The sunset effect does not change the volume

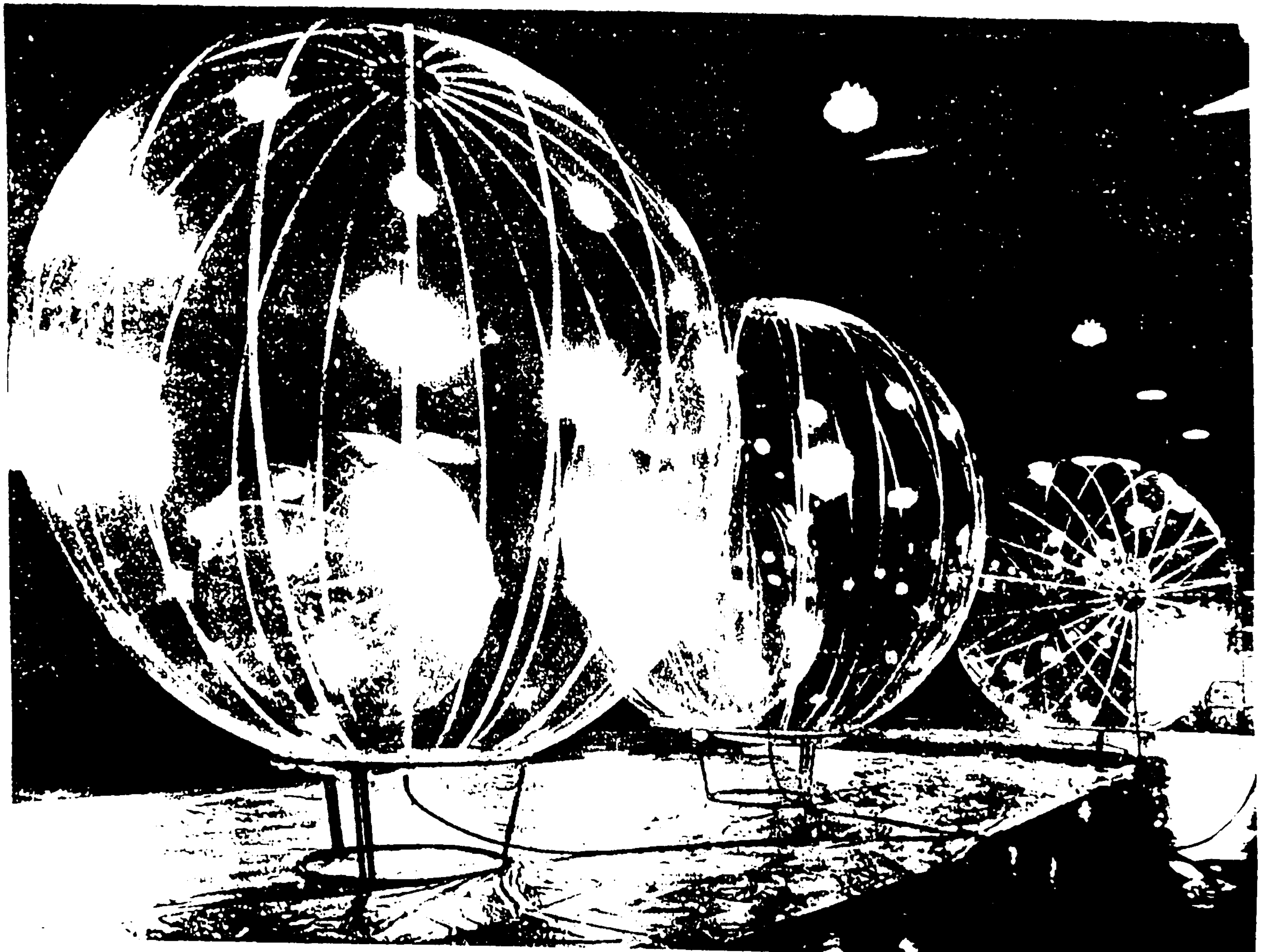

Figure 1. Mylar Superpressure Balloons

of the balloon more than a differential amount (resulting from the reversible reaction of the envelope to small changes in overpressure). Equilibrium is therefore maintained without expenditure of ballast. The balloon remains aloft until its reserve of overpressure is depleted by leakage and diffusion of the gas through the envelope, or by excessive cooling of the lifting gas to beyond the reserve of superpressure.

The program of the National Center for Atmospheric Research (NCAR) and of the French Government has resulted in some 1,000 launches of such balloons and the accumulation of a considerable understanding of the physics of their flight. It is seen that as regards duration, they fly best at altitudes in the low stratosphere; at lower altitudes they run into weather problems (rainfall and iceing); and at higher altitudes they are subject to ultraviolet (UV) degradation of the material. In the low stratosphere (100 millibars, mb), flights of six months duration are common. Figures 2 and 3 show typical flights.

At the 100-mb level, the payload weight is a function of the size of the carrying balloon. As the balloon volume increases with r^3 while the balloon weight increases only with r^2, the larger balloons are more efficient carriers of payload. Taking as an example a balloon made of 5-mil Mylar having a skin weight of 210 g/m^2, Figure 4 shows the payload carrying capacity of such a balloon as a function of balloon diameter. Note that balloons of less than 9 meters cannot reach 100 mb even without a payload, and as the diameter approaches 15 meters the payload weight is already over 100 kg. This calculation is, however, only theoretical as it does not take into account the limitations placed on the size of such a balloon by skin stresses.

During the diurnal cycle, the temperature of the helium varies considerably, being heated during the day to well above ambient temperature by sunlight (both directly incident and reflected from underlying clouds), and cooled at night to below the ambient temperature by infrared (IR) radiation of the Mylar skin to the colder space environment. As the balloon

MONTHLY WEATHER REVIEW

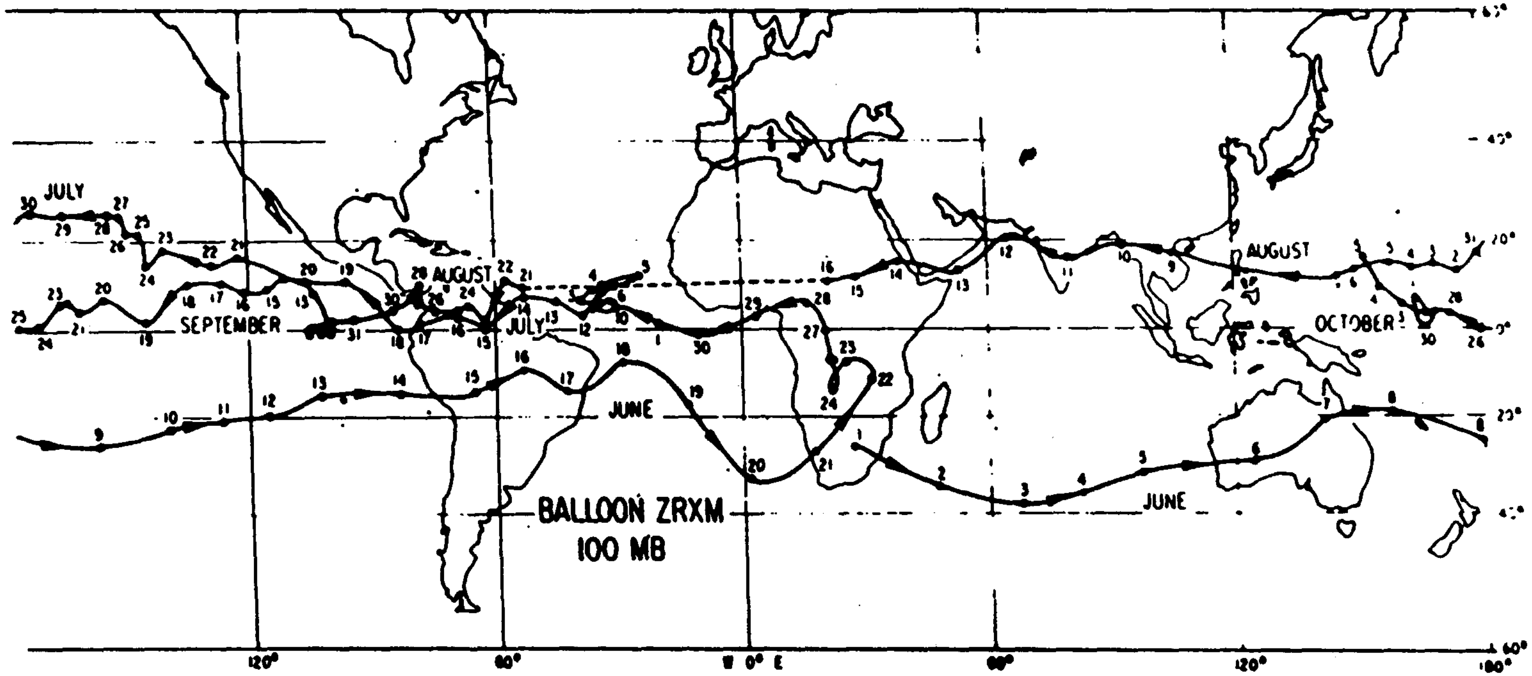

Figure 2. Trajectory of Superpressure Balloon at 56,000-ft Altitude (1 June to 5 October 1968)

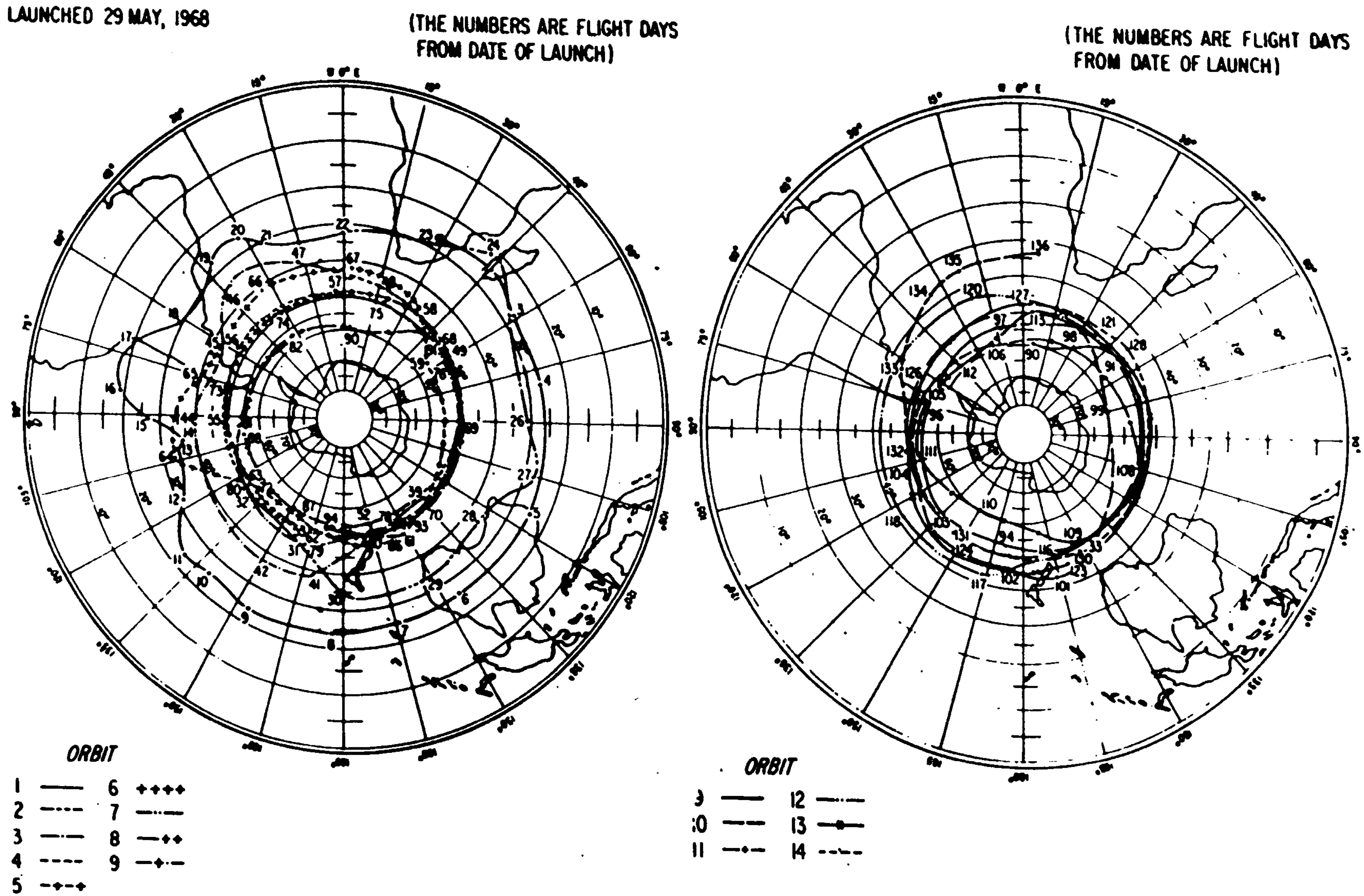

Figure 3. Trajectory of Superpressure Balloon at 56,000-ft Altitude (Launched May 29, 1968)

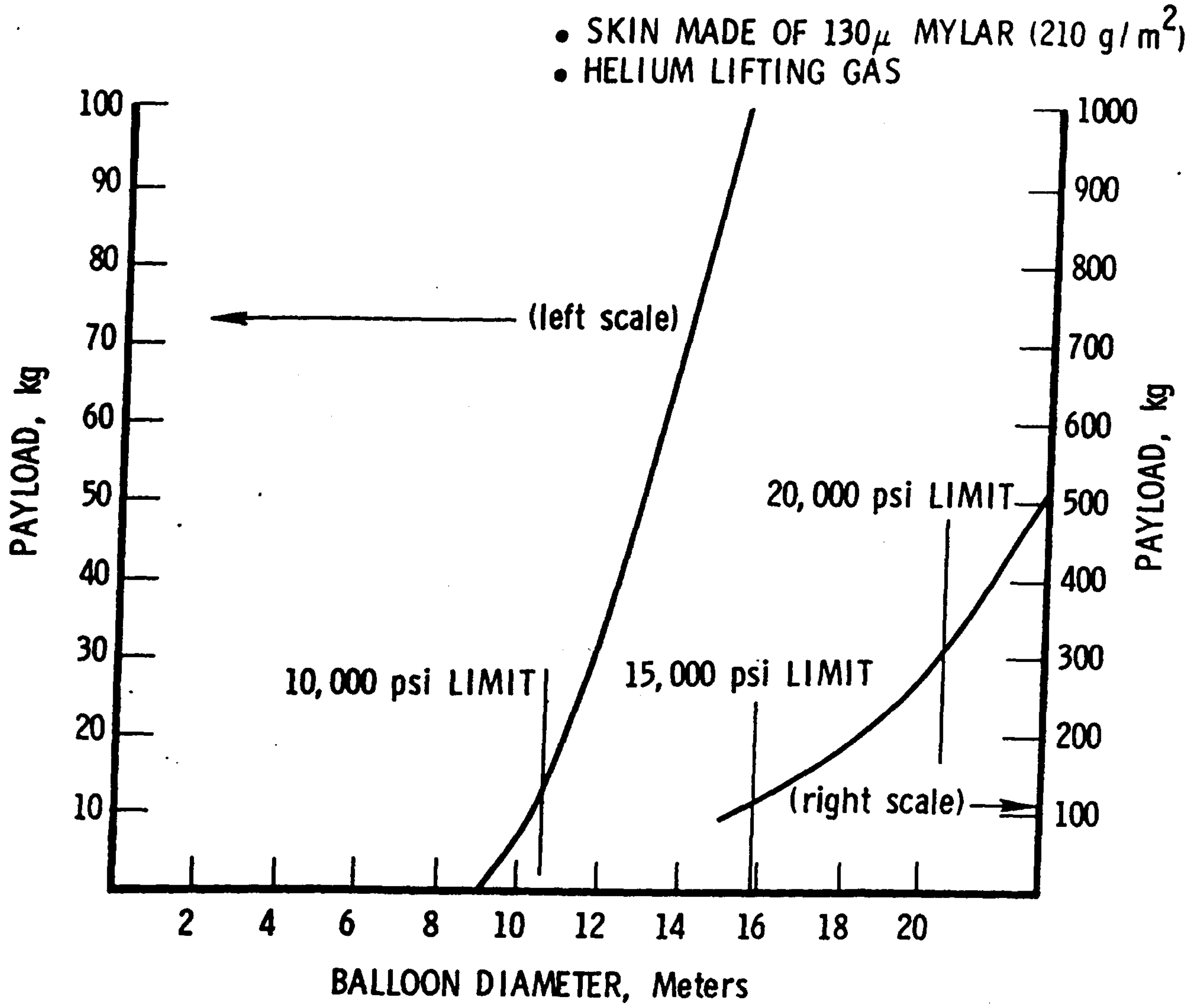

Figure 4. Theoretical Payload of Superpressure Balloon at 100 mb (56,000 ft)

is completely sealed, no gas can escape, and the variation of gas temperature for a vessel of constant volume is directly translated into a proportional variation in helium gas pressure:

$$\frac{P_{min}}{T_{min}} = \frac{P_{max}}{T_{max}}$$

The balloon skin is stressed by the "superpressure" or differential pressure across the envelope:

$$\Delta p = P_{gas} - P_{ambient}$$

The gas law can therefore be put in terms of Δp (where P_a is ambient pressure):

$$\Delta p_{max} + P_a = \left(\Delta p_{min} + P_a\right)\left(\frac{T_{max}}{T_{min}}\right)$$

$$\frac{\Delta p_{max}}{P_a} + 1 = \left(\frac{\Delta p_{min}}{P_a} + 1\right)\left(\frac{T_{max}}{T_{min}}\right)$$

If we assume that at the lowest nightime temperature Δp_{min} approaches zero, then:

$$\Delta p_{max} = P_a\left(\frac{T_{max} - T_{min}}{T_{min}}\right)$$

This gives the balloon superpressure as a function of ambient pressure and gas temperature. The skin stress on the balloon is given by:

$$\sigma = \frac{286(\Delta p)(r)}{t}$$

where (Δp) is the overpressure in millibars, (r) the balloon radius in meters, and (t) the skin thickness in mills. For Mylar balloons the limiting stress is 10,000 psi. The Δp is a function of the diurnal temperature variations and therefore a function of (t) the skin thickness; as the thickness increases, the balloon becomes more absorptant in the visible and the daytime gas temperature (and superpressure) increases. For values of t = 5 mils, flight data has shown that diurnal gas temperature swings of 60°C are to be expected. This leads to a Δp_{max} of:

$$\Delta p_{max} = (100)\left(\frac{60}{180}\right) = 33\text{mb}$$

or a maximum balloon size of

$$r_{max} = \frac{(10,000)\ (5)}{(286)\ (33)} = 5.3 \text{ meters}$$

This would be a 10.6-meter balloon, which as seen on Figure 4 limits the payload at 100 mb to only ≈ 15 kg. It is important to note here that a modest increase in balloon strength has a dramatic effect on balloon size and payload. For the same 33-mb variation, a balloon skin capable of 15,000 psi would allow construction of a balloon having 1.5 times the radius capable of carrying over 100 kg of payload; a 20,000-psi material would carry a ≈ 300 kg payload. It must be underscored that in increasing the strength, the diurnal temperature swings must not be increased proportionally; otherwise the gains are nullified by the increase in Δp. Clearly, stronger materials are the key to larger payloads.

The development of a new high-strength material (Kevlar) has made the design of such heavy payload balloons a realizable goal. The characteristics of Kevlar are shown in Table 1, reproduced from a Du Pont circular, and in Figure 5, reproduced from a Sheldahl study. The possibility of supporting a one-ton payload at 100 mb is well within the strength limitations of a balloon having Kevlar as its primary structural element. It is this potential that gave rise to the ATMOSAT program.

ATMOSAT, the Atmospheric Satellite, is to be designed to carry a one-ton payload in the low stratosphere for durations up to one year. The balloon is to be made of a "sandwich" of materials:

a. An inner layer of Kevlar cloth to sustain the pressure loads

b. A layer of bilaminated Mylar to contain the helium

c. An outer sheet of aluminized Tedlar to limit the diurnal variations of helium temperature, and to protect the Kevlar and Mylar from UV radiation.

The lifting properties of the Kevlar ATMOSAT are shown in Figure 6 for flight at 100 mb (56,000 feet, 160 g/m^3). In this figure the skin strength is expressed in "pounds/inch," which is the skin stress (σ) in psi multiplied by the skin thickness (t) in inches. For the 5-mil Mylar, a 10,000-psi limit corresponds to 50 lb/inch. Even the lightest ATMOSAT material has 175-lb/inch, while the strongest has 700-lb/inch strength, corresponding to 140,000-psi stress.

The thirty-meter ATMOSAT is therefore seen to be capable of carrying a one-ton payload into the stratosphere. The goal of the FY'76 program is to collect the ground and flight data needed to build that vehicle.

The overview program plan is shown in Figure 7. Note the emphasis on flight testing to provide hard data on the performance of 3.5- and 10-meter ATMOSATS. This program has been developed in close cooperation with the Service d'Aeronomie CNRS and the French Space Administration (CNES), which are contributing significant resources.

Table 1. Properties of Kelvar

1. **What is "Kevlar" 29?**
   - "Kevlar" 29 DP-01*, tested as Fiber B, is the Du Pont trademark for a new high strength, intermediate modulus organic fiber designed for special applications.

2. **What are the important characteristics of "Kevlar" 29?**
   - "Kevlar" 29 combines very high tensile strength and resistance to stretch with light weight and good toughness. It has good environmental stability, flame resistance, and useful properties over a wide range of temperatures.

3. **Is "Kevlar" 29 available in commercial quantities?**
   - Yes. The Richmond, Virginia plant has been in operation since early 1972 and was expanded in 1973.

4. **In what form is "Kevlar" 29 sold?**
   - "Kevlar" 29 is available from Du Pont as a continuous filament yarn in a range of deniers and types specifically tailored to the requirements of its various uses.

5. **Where is "Kevlar" 29 used?**
   - "Kevlar" 29 is being used or evaluated for a wide variety of high performance applications in cables, ropes, broadwoven fabrics, webbings and tapes, either alone or in combination with conventional fibers.

*The temporary designation assigned by FTC pending action on application for a new generic name.

"KEVLAR" 29 YARN PROPERTIES

DENSITY	• 1.44 gm/cc
FILAMENT DIAMETER	• 0.00047 in
DENIER PER FILAMENT	• 1.5
*BREAK ELONGATION	• 3-4%
*TENSILE STRENGTH	• 400,000 psi
TENACITY	• 22 gpd
**SPECIFIC TENSILE STRENGTH	• 8 x 10⁶ in
*MODULUS	• 9 x 10⁶ psi 480 gpd
**SPECIFIC MODULUS	• 2.3 x 10⁸ in
BOIL-OFF SHRINKAGE	• Essentially zero
DRY HEAT SHRINKAGE @ 320°F.	• Essentially zero
SHRINKAGE TENSION @ 320°F.	• Essentially zero
TEXTILE PROCESSIBILITY	• Can be handled in all textile processes • Yarns retain 90% of tensile strength after weaving • Knot strength is 37% of straight tensile strength
FLAMMABILITY	• Inherently flame resistant • Self-extinguishing • Does not melt • Chars at 800°F
TEMPERATURE RESISTANCE	• Useful properties from −420°F to +500°F

*Dry Yarn Test
**Yarn property divided by density.

TYPICAL PROPERTIES

Tension Members

		Brk. Str. (lbs)	Brk. Elong. (%)
Unimpregnated			
1/2" dia. strand rope	Kevlar* 29	14,300	16.0
	Dacron* polyester	6,900	28.0
3/8" dia. braid	"Kevlar" 29	13,600	4.5
	Dacron*	7,000	—
9/16" dia. parallel strand	"Kevlar" 29	29,375	3.3
5/8" dia. parallel strand	Dacron*	16,000	10.0
Impregnated (Urethane)			
9/64" dia. cable	"Kevlar" 29	2,500	—
5/32" dia. cable	Stainless Steel	2,400	—

Broadwovens

		"Kevlar" 29	Nylon
Weight, oz/yd²		6.3	12.0
Thickness, in.		.017	.026
Tensile—Ravel Strip, lbs/in.	—Warp	650	660
	—Fill	600	640
Tongue Tear (coated), lbs	—Warp	185	60
	—Fill	200	60

Narrow Wovens

	Weight (oz/yd)	Strength (lbs)
Webbing		
"Kevlar" 29	1.87	15,000
Dacron*	3.30	9,500
Tapes		
"Kevlar" 29	0.40	2,600
Dacron*	0.84	2,000
Nylon	0.88	2,500
Ribbons		
"Kevlar" 29	0.20	1,310
Nylon	0.32	485

*Du Pont trademark

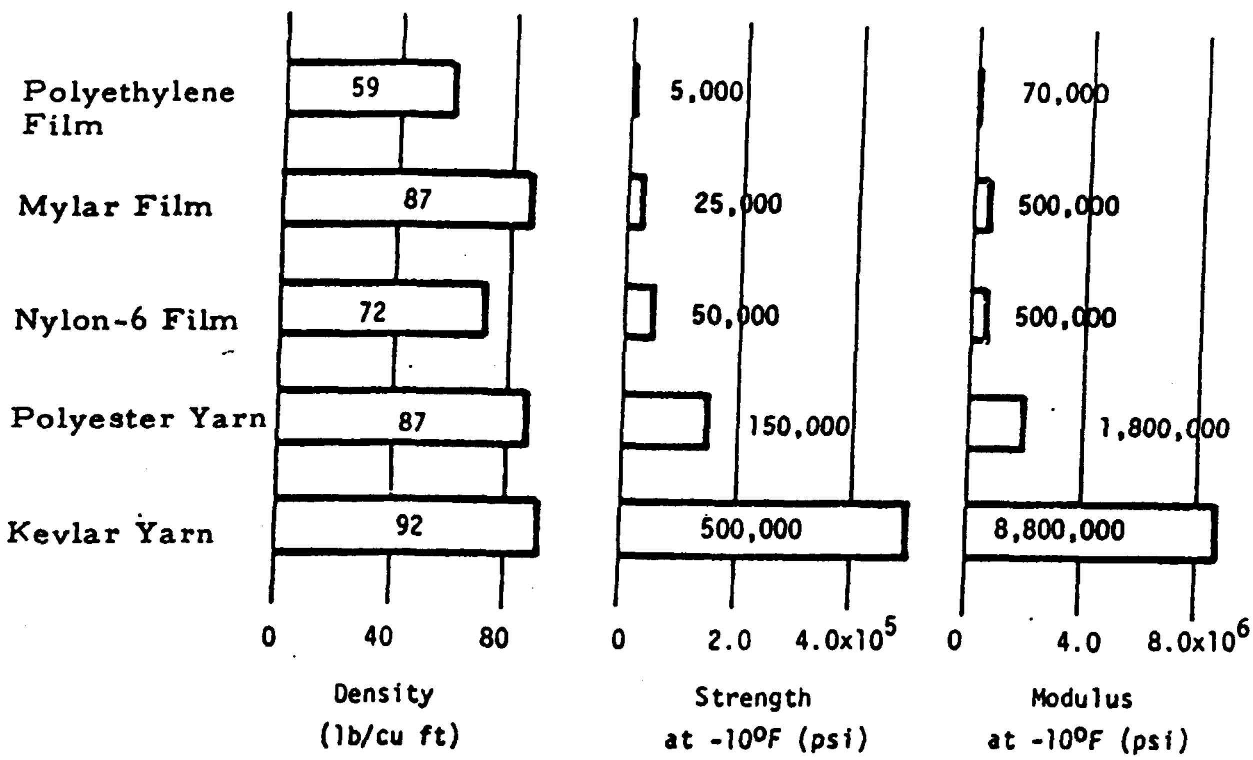

Figure 5. Candidate Materials for Balloon Envelopes

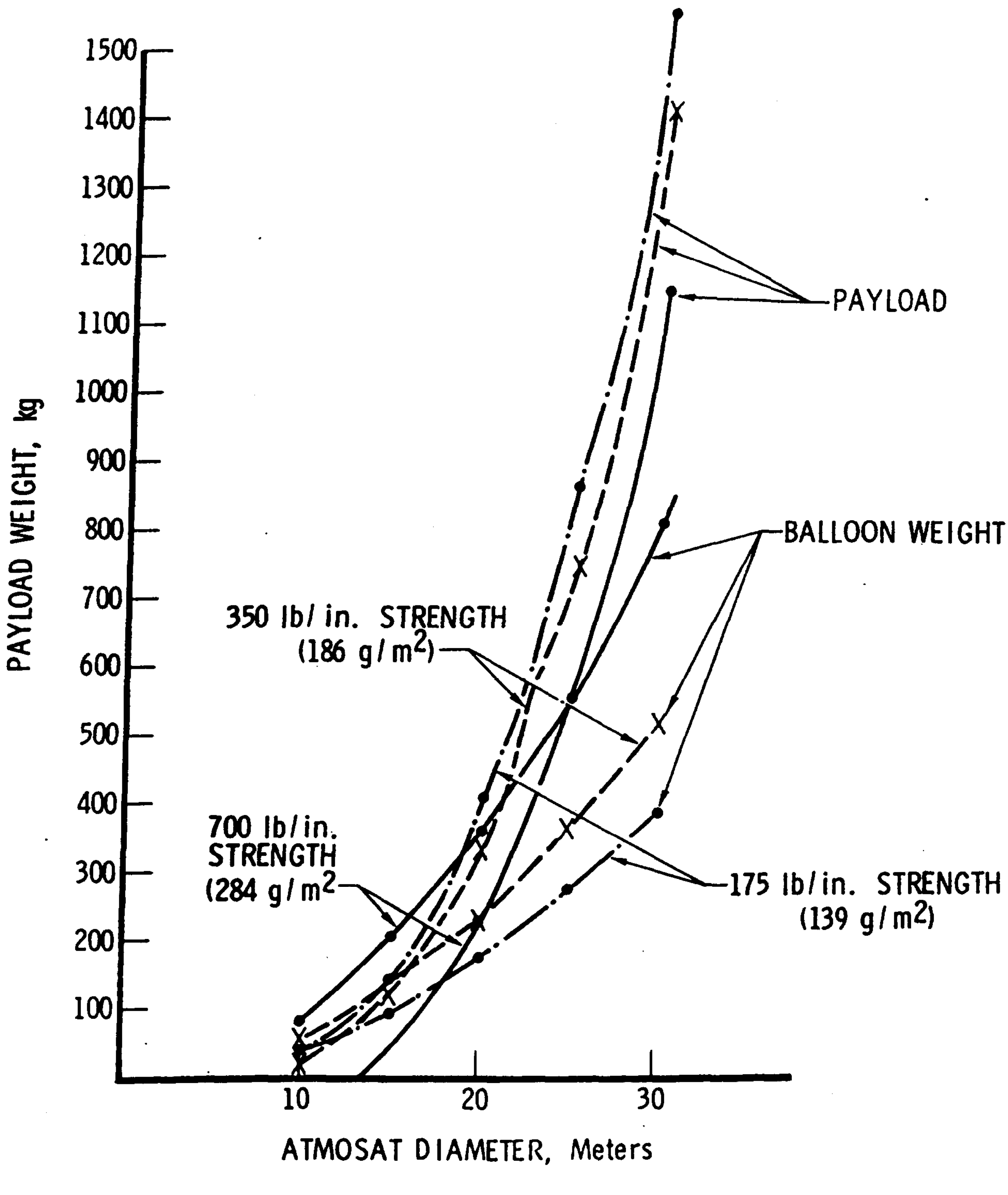

Figure 6. ATMOSAT Load Capacity at 100 mb (56,000 ft)

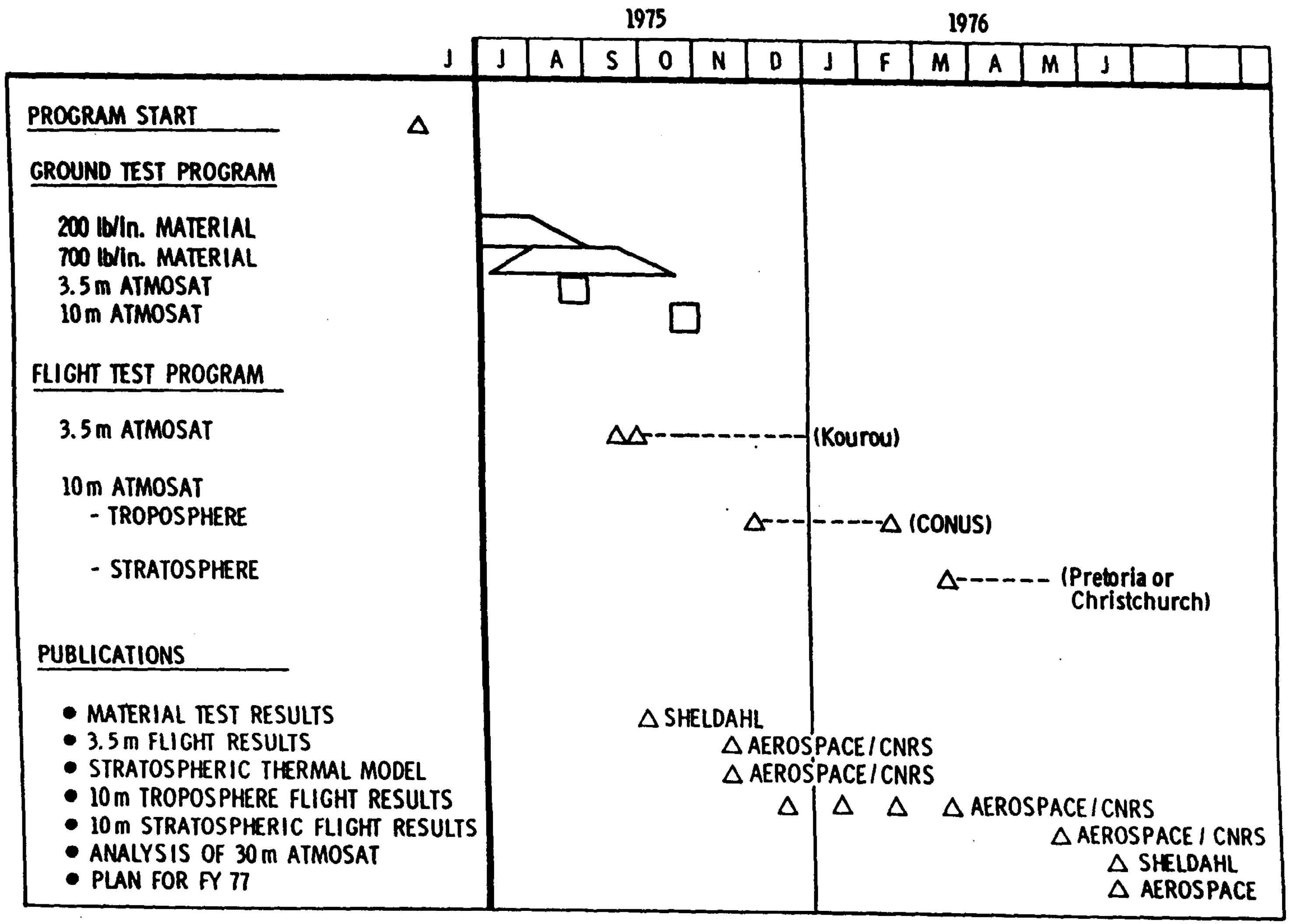

Figure 7. ATMOSAT Program Schedule for FY'76

II. THE 3.5-METER ATMOSAT TEST PLAN

Two 3.5-meter ATMOSAT balloons are presently under construction at Sheldahl Corporation. These balloons will be extensively tested at the manufacturer's facility and then delivered to Aerospace for flight test. Flight test will take place at the French National Space Center at Kourou, French Guyana in September 1975. The principal goals of the flight are:

a. Balloon supertemperature (gas temperature minus ambient air temperature) measurements over several diurnal cycles

b. Confirmation of the structural integrity of the balloon during inflation at -80°C

c. Long-term leak measurements in the low stratosphere.

As a 3.5-meter ATMOSAT is too small to fly freely at the 100-mb (56,000-ft) flight level, it will be suspended from a ten-meter mylar balloon. The flight train is as shown in Figure 8. Two identical flights are planned.

Figure 9 shows the system as it would look prior to launch. The photos were taken in September 1974 at Kourou during tests of the 10-meter Mylar balloon which will be used as a carrier balloon in these flights. The carrier balloon, inflated such that it will be fully superpressurized at 100 mb is seen in the foreground; the flight train leading into the shelter is also seen. The radar reflector is just under the main balloon followed by two aluminized cones protecting the electronics and battery packages. The smaller balloon seen in the shelter will be replaced by the 3.5-meter ATMOSAT for the 1975 flights.

For the 3.5-meter ATMOSAT tests, Telemetry Package No. 1 will measure:

a. Ambient air temperature (T_a)

b. Mylar balloon helium temperature (T_g)

c. Superpressure of the Mylar balloon (Δp)

d. Pressure altitude (P_a).

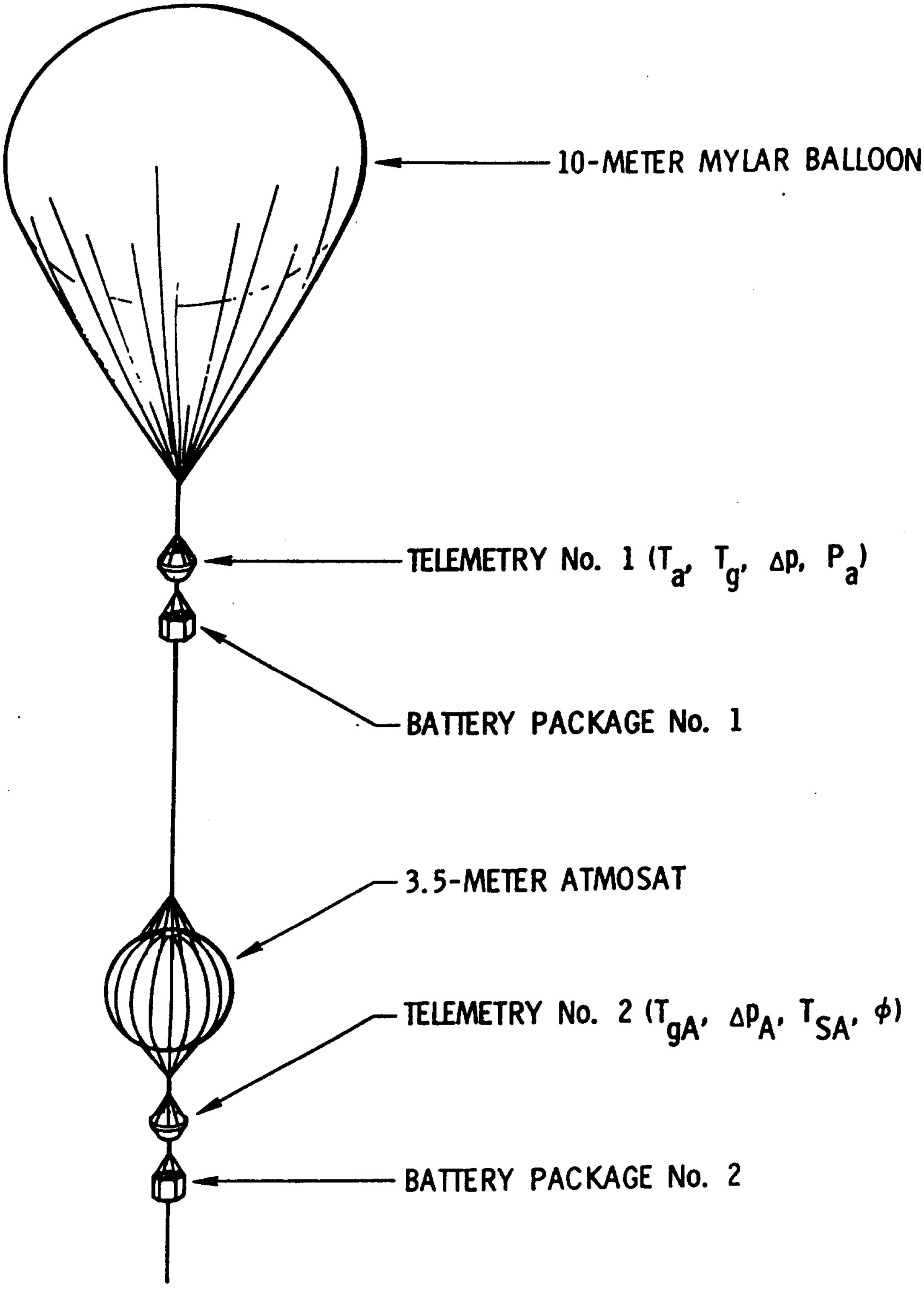

Figure 8. 3.5-Meter ATMOSAT Flight Train

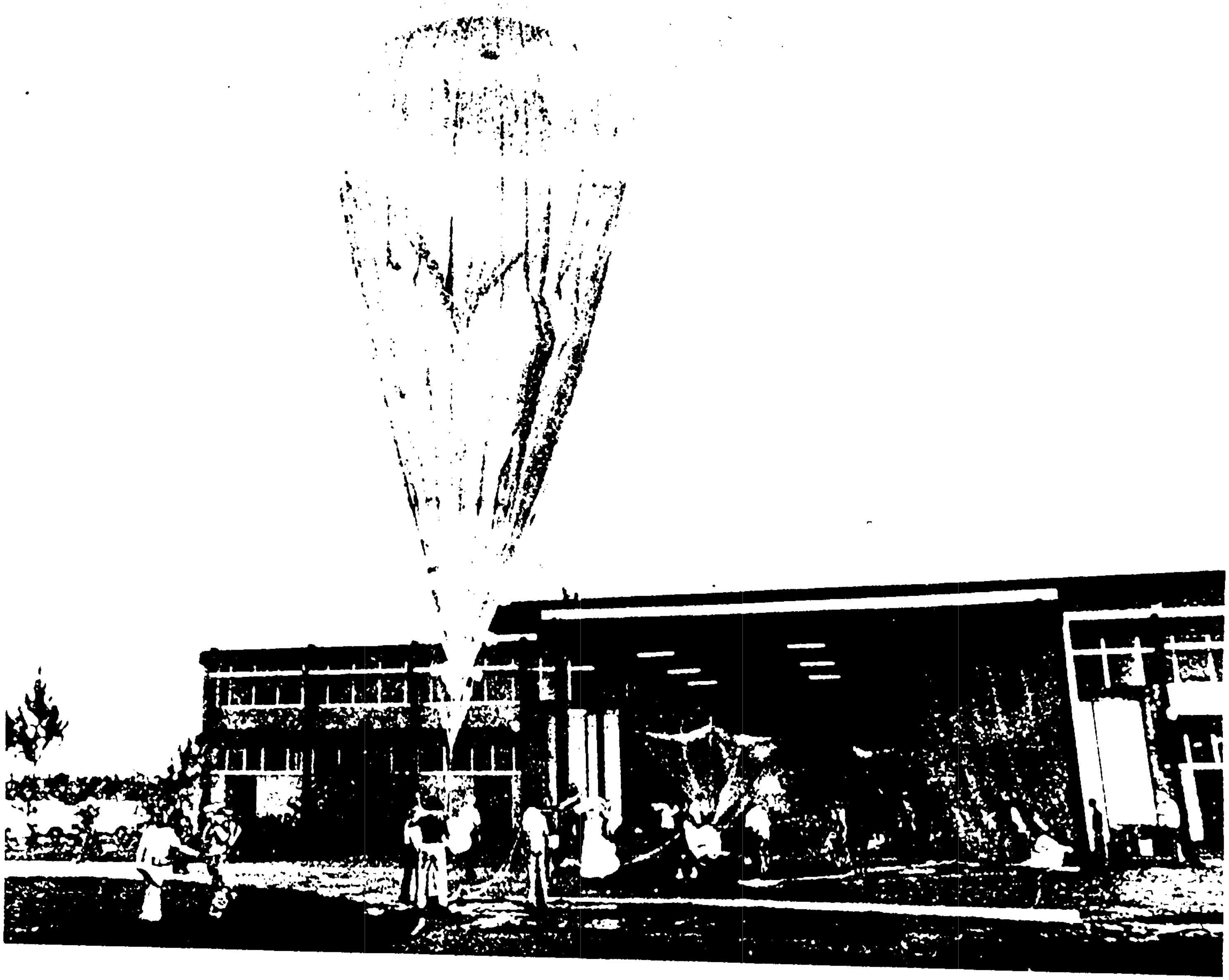

Figure 9. Launch Configuration of 3.5-Meter ATMOSAT Test Flight

Telemetry Package No. 2 will measure:

a. ATMOSAT helium temperature (T_{gA})
b. ATMOSAT superpressure (Δp_A)
c. ATMOSAT skin temperature (T_{sA})
d. Solar elevation angle (ϕ)

The two battery packages will supply power for nocturnal telemetry for at least one week; solar cells will power the systems during daylight hours for the duration of the flight.

The ATMOSAT will remain at the 100-mb level as long as the Mylar carrier balloon remains fully inflated. The flight duration is expected to be several months if the carrier balloon arrives at its ceiling altitude without significant leaks.

The data from the tests will be correlated with other information collected during the flight to establish the thermal environment of the balloon:

a. Local radiosonde data
b. Satellite cloud photographs and local cloud observations
c. Radar reconstruction of the early trajectory.

This information will allow a good estimation of the visible and IR flux into the balloon. The variations of balloon gas temperature and superpressure resulting from changes in this flux will show how strong a larger ATMOSAT must be in order to survive in free flight (without either depressurization or explosion).

The data will be reduced and published jointly by Aerospace and the Service d'Aeronomie. To complement the data and improve the computer model of the balloon's thermal environment, three additional Mylar balloons will be flown as part of the same program. These 5.6-meter diameter balloons will be similarly instrumented. Each of these balloons will be tracked by the space center's radars while they are in range. Cine-theodolite photos will be taken during the ascent phase and occasionally at ceiling. The worldwide HF balloon tracking network will collect telemetry data during the balloons' lifetimes. The data is sent to a central collection bureau at CNES (Toulouse, France) and then sent to Aerospace and the Service d'Aeronomie for reduction and analysis.

III. THE TEN-METER ATMOSAT TEST PLAN

Prior to the production of the 30-meter ATMOSATs which will carry a one-ton payload into the stratosphere, a test program using less ambitious 10-meter models will be undertaken. Considerable experience has been accumulated to date on the in-flight testing of Mylar superpressure balloons, and this experience will be the basis of the new test program, as discussed in Section II.

It has been the previous practice to qualify a new balloon design by flying some ten to twenty prototypes at the mission altitude, each balloon equipped with a simple high frequency (HF) telemetry transmitter sending data back to ground stations. These balloons fly until they lose lift and then fall into the sea; no recovery is attempted. This practice was acceptable when the all-up costs of a balloon flight were of the order of one to two thousand dollars. With the ATMOSAT vehicle, the cost of the balloon itself is of the order of 20 thousand dollars for even a 10-meter test balloon. A more efficient use of the balloons in the developmental phase is therefore mandatory.

The first production 10-meter balloon will therefore be used for extensive ground and low altitude flight testing before it is committed to a non-recoverable flight test in the Spring of 1976. The most important aspect of the flight test program is to thoroughly understand the thermodynamics of the balloon in all possible flight situations; this is to assure that ATMOSAT will never fall due to thermally induced depressurization (highly negative super-temperature of the helium), and that the scientific payload weight is not penalized by overly conservative balloon design (i.e., excessive Kevlar used to make the ATMOSAT much stronger and therefore heavier than it need be).

ATMOSAT is designed such that the diurnal variations of the super-temperature should be minimized, and that the lifting helium would always be kept at or above the temperature of the ambient air. Minimizing the variation will limit the strength needed in the balloon; keeping the temperature above the ambient will induce a beneficial cooling due to forced convection. The Service d'Aeronomie is producing the thermal models which will allow extrapolation from the observed data taken at 900, 700, and 500 mb during the low altitude test program, to produce predictions of thermal performance at 200 mb, 100 mb, and above. These models will be based on the flights already made in Kourou in September 1974 and the flights planned in cooperation with Aerospace for September 1975.

Consideration is being given to equipping the balloon with a removable "beanie" such that the top hemisphere could be covered with materials having various values of solar absorptivity and IR emmisivity, in order to evaluate the effects of particular combinations of values.

Table 2 shows some preliminary calculations by the Service d'Aeronomie of the worst-case supertemperature variations at 100-mb altitude.

Balloon Design No. 1 is the baseline ATMOSAT design being used for the 3.5-meter test spheres. The thermal properties are the result of an outer balloon skin comprising a sheet of one-mil thick clear Tedlar, with a layer of aluminum some 1000 Å thick on its inner surface. Note that the superpressure is not as low as it could be (although acceptable), but that this design suffers from a significantly negative nocturnal supertemperature. This has several disadvantages:

a. At altitudes of 200 mb and below, the cold gas temperature promotes iceing on the balloon skin with possible loss due to mass accumulation overwhelming balloon lift.

b. At 100 mb, it exposes the skin to temperatures of -95°C where the Mylar is brittle, causing potential leakage.

Balloon Design No. 2 would put the aluminum coating on the outside of the Tedlar, and assumes no change in α. The emmisivity, which is due to the Tedlar (which is now covered) drops in this model to nearly zero (0.05 is assumed).

Design No. 2 has the advantage of a less negative nocturnal supertemperature, but a higher total temperature (and pressure) variation makes it

Table 2. Extremes of ATMOSAT Supertemperature at 100 mb and Resulting Superpressures

Assumptions: Altitude - 100 mb (density = 180 g/m^3)
Ambient Temp - -80°C
Nocturnal IR input - 80 w/m^2 from clouds
Daytime IR input - 220 w/m^2 from clouds
Daytime Solar input - 2520 w/m^2 from sun and clouds (albedo ≈ 1.0)

Design No.	Balloon Design	Supertemperature (°C) Nightime	Supertemperature (°C) Daytime	Total Gas Temp Variation (°C)	Maximum Daytime Superpressure in mb (if minimum = 0 mb)
1	α = 0.12 e = 0.45	-15	+50	65	37
2	α = 0.12 e = 0.05	- 5	+77	82	44
3	α = 0.08 e = 0.05	- 5	+58	63	34
4	Beanie α = 0.12 e = 0.05 Bottom α = 0.12 e = 0.45	- 3	+70	73	37
5	Beanie α = 0.08 e = 0.05 Bottom α = 0.12 e = 0.45	- 3	+63	66	35
6	Beanie α = 0.12 e = 0.45 Bottom α = 0.12 e = 0.05	-20	+47	67	39
7	α = 0.20 e = 0.45	-15	+76	91	53

unattractive. If, however, in transferring the aluminum to the outer surface (thereby eliminating the solar radiation path through the Tedlar), the solar absorptivity improved to 0.08, then the situation improves considerably (Design No. 3). The balloon is not very negative at night, and the total pressure variation is less than that for any other candidate.

The use of the "beanie" on the top hemisphere is shown for Design Nos. 4 through 6. Design No. 5 appears best, in which the balloon is highly reflective and poorly emissive upwards, and has moderate reflectivity and emissivity downward.

As the actual values of the balloon's α and e are not certain to be identical to those shown in tests of samples of the material, the actual values must be determined in flight. Design No. 7 shows the dramatic increase in balloon stress if the α were in fact 0.20 instead of 0.12.

The recoverable low altitude evaluation tests will measure the actual temperature variations, the thermal time constant, effects of aging and handling of the outer skin, and the effects of various "beanies" in minimizing the effects of supertemperature variations on balloon performance. Table 3 shows the computed temperatures of Design Nos. 1 through 6 at 800 mb. Note that the effects of varying values of α and e are clearly discernable at that altitude.

The flight plan involves flights over the various types of terrain (large bodies of water, deserts, mountains, snow fields, forests, plains) at altitudes ranging from 1,000 to 15,000 feet. Careful track of the surrounding thermal inputs is made (cloud cover above and below, solar elevation in daytime, air temperature, velocity of the balloon with respect to the air, etc.). The thermal response of the balloon to its environment is noted by measuring gas temperature and several skin temperatures at regular intervals during each flight. The data is then forwarded to the Service d'Aeronomie for analysis. The result will be an accurate prediction of the thermal situation to be faced by an operational ATMOSAT in the stratosphere, and a prediction of the

Table 3. Extremes of Supertemperature at 800 mb and Resulting Superpressures

Assumptions:

Altitude - 800 mb (density = 970 g/m^3)
Ambient Temp - 15°C
Nightime IR - 390 w/m^2 from below, 200 w/m^2 from above
Daytime IR - 460 w/m^2 from below, 390 w/m^2 from above
Solar flux - 1200 w/m^2 from above, albedo of 0.8

Design No.	Balloon Design	Supertemperature (°C) Nightime	Daytime	Total Gas Temp Variation (°C)	Maximum Daytime Superpressure (if minimum = 0 mb and no CREW action to limit Δp)
1	α = 0.12 e = 0.45	-11	+19	30	87
2	α = 0.12 e = 0.05	- 3	+30	33	93
3	α = 0.08 e = 0.05	- 3	+22	25	71
4	Beanie α = 0.12 e = 0.05 Bottom α = 0.12 e = 0.45	- 2	+25	27	75
5	Beanie α = 0.08 e = 0.05 Bottom α = 0.12 e = 0.45	- 2	+21	23	64
6	Beanie α = 0.12 e = 0.45 Bottom α = 0.12 e = 0.05	-15	+21	36	106

Note - Design limit of the 10 meter ATMOSAT is 500 mb, flight limit is 170 mb.

load carrying capacity, altitude range, and lifetime of the subsequent stratospheric flights. Upon completion of the low altitude program, the first 10-meter ATMOSAT would be equipped with a small scientific payload and flown in the stratosphere. This flight, which would not be recoverable, would be launched either at the NCAR test facility at Christ Church, New Zealand, or at the CNES site at Pretoria, South Africa (these sites assure a good injection into the temperate zone jet stream).

A. FLIGHT CONFIGURATION OF THE LOW ALTITUDE SERIES

The flight train is as shown in Figure 10. The configuration is similar to the classical hydrogen balloon shown in Figure 11, a hydrogen balloon of similar size seen in flight (Calvados, France June 1, 1975).

The gas valve at the balloon crown is a standard 13-inch diameter balloon valve flown on hundreds of stratospheric balloons. The balloon superpressure is monitored on board by a pressure gauge connected to a hose leading to the balloon. The superpressure can be reduced by manual action of a valve at the lower end of that hose. Superpressure is manually limited to less than one-third of the design pressure of the balloon.

The electrical bundle descending from the balloon contains the command lines for the 13-inch helium valve and the sensor lines from thermistors inside the balloon that measure skin and gas temperatures. The measurements will be recorded manually following a pre-planned program for each flight.

A typical set of measurements, to be repeated each 30 minutes, would include:

1) Balloon location
2) Balloon altitude (and rate of climb, if any)
3) Balloon superpressure
4) Ambient temperature

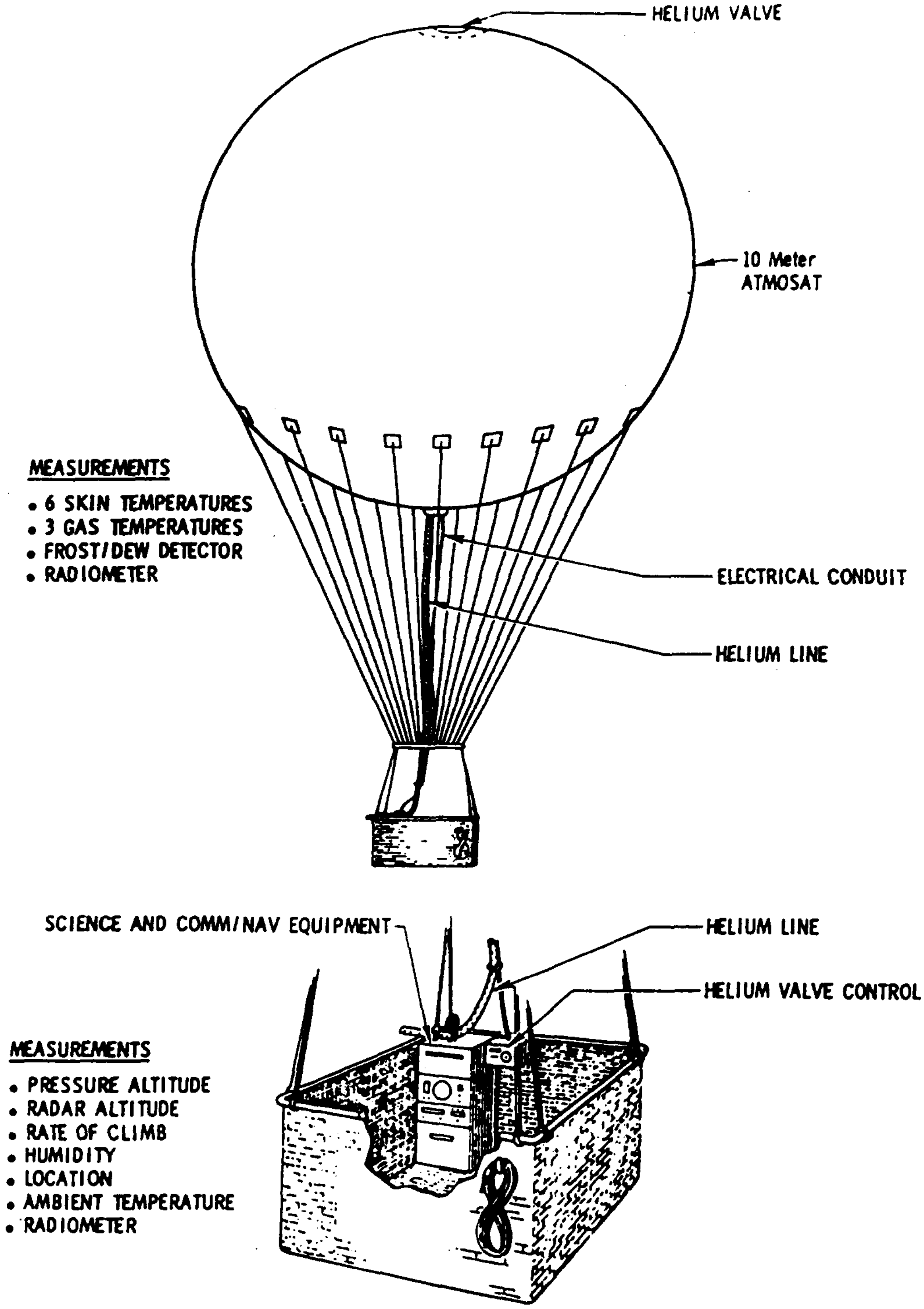

Figure 10. 10-Meter ATMOSAT Flight Train

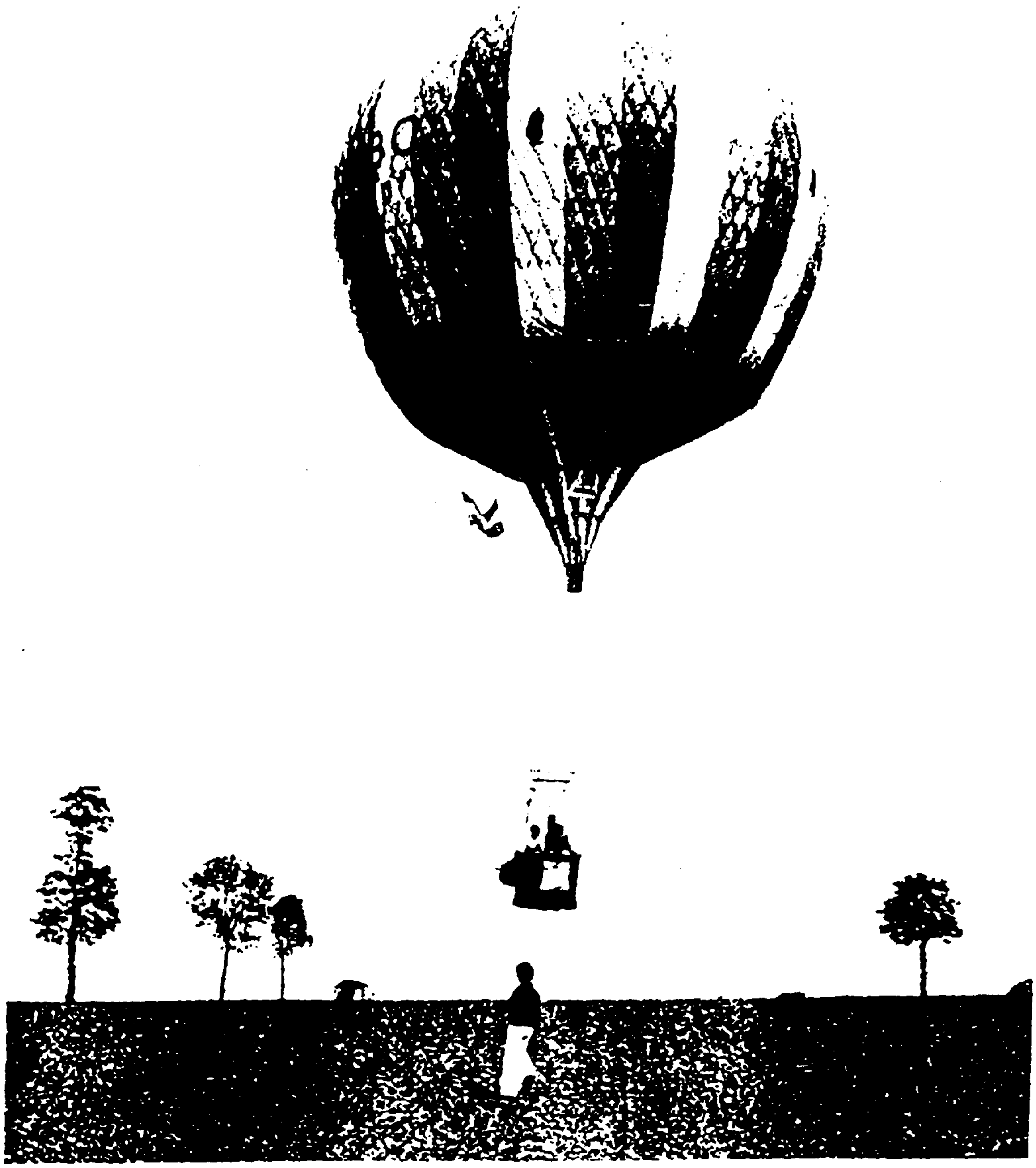

Figure 11. Classical Hydrogen Balloon

5) Each skin and gas temperature sensor

6) Photos of surrounding clouds and ground

7) Comments of observer

A typical flight would make a series of these observations at each of a set of discrete altitudes.

As the collection of the thermal data will not involve a great deal of crew activity, it is planned to carry aboard each flight a complement of scientific equipment to make in-situ measurements of the lower atmosphere. The scientific program is now under discussion and will be the subject of a subsequent report. Payloads of up to 50 kg of scientific equipment are planned.

B. GONDOLA EQUIPMENT

To perform the low altitude flights, the gondola will be equipped with a number of flight systems:

1) Flight Control System
   a) Aircraft Com/Nav set
   b) Aircraft transponder with encoding altimeter
   c) Radar altimeter
   d) Aircraft strobe lamp
   e) Pressure altimeter and rate-of-climb indicator
2) Balloon Technology System
   a) Balloon superpressure gauge
   b) Helium valve control unit
   c) Thermistor readout meter
   d) Cameras, log books, data sheets and procedures
3) Science System--A set of scientific instruments to be supplied by interested experimentors
4) Power System--Three independent sources of 14-volt power to energize all systems using rechargeable batteries as the two primary supplies and lithium cells as the backup supply.

C. LOW ALTITUDE FLIGHT GOALS

The tropospheric (low altitude) flights of the 10-meter ATMOSAT will then have these goals:

1) Collection of the necessary thermal data for design of the 30-meter stratospheric ATMOSAT
2) Accumulation of technical data on launch, flight, and recovery techniques of the new type of vehicle
3) Scientific observations of the environment using instruments provided by interested laboratories or agencies which are now being contacted in request of experiments.

An interesting additional feature is the potential of these flights to set new world records for lighter-than-air travel. The world aviation records, kept by the Fédération Aéronautique Internationale (FAI), include a section for free balloons. The present flight records are shown in Table 4. The ATMOSAT flights are candidates to better the records for Classes A3 through A10. The 10-meter ATMOSAT has 524 m^3 volume and therefore falls into Class A3. Such a balloon would claim a record for its class and for any higher class (larger balloon) which it was able to outperform. The existing distance and duration records, some of which are within the reach of the first ATMOSAT, are held by the USSR and Germany. Their capture by the United States would be a side benefit to the ATMOSAT development program. A 48-hour flight of some 550 miles (confined to the southwestern desert) would capture <u>two</u> world records (A3 distance and duration); a flight of 65 hours over 1,100 miles would capture <u>four</u> additional world records, etc.

D. ATMOSAT LOW ALTITUDE STABILITY

At the 800-mb level the horizontal flight will be perturbed by vertical winds and by precipitation.

1) The displacement of a superpressure balloon due to vertical winds is derived by Lally (NCAR TN-28) as

$$\Delta z = \frac{1.15\, C_D\, T\, v^2}{r}$$

Table 4. FAI World Records, Class A Free Fall Balloons (General)

	Class A1. under 250m^3		Class A2. 250 to 400m^3	
Duration	–	–	A. Dollfus	France
	–	–	3 May 1953	4.0 min
Distance	Wilma Piccard	USA	A. Dollfus	France
	12 Aug 1972	28.3 km	3 May 1953	208.6 km
Altitude	Don Piccard	USA	D. Piccard	USA
	25 Jul 1960	1140m	24 Aug 1962	5409.2m

	Class A3. 400 to 600m^3		Class A4. 600 to 900m^3	
Duration	S. Sinoveev	USSR	F. Bourlouzki	USSR
	30 Mar 1941	46.10 min	3-6 Apr 1939	61.30 min
Distance	G. Cormier	France	F. Bourlouzki	USSR
	1 Jul 1922	804.1 km	3-6 Apr 1939	1701.8 km
Altitude	Tracy Barnes	USA	Tracy Barnes	USA
	10 May 1964	11780m	10 May 1964	11780m

	Class A5. 900 to 1200m^3		Class A6. 1200 to 1600m^3	
Duration	F. Bourlouzki	USSR	B. Nevernov	USSR
	3-6 Apr 1939	61.30 min	13-16 Mar 1941	69.20 min
Distance	F. Bourlouzki	USSR	B. Nevernov	USSR
	3-6 Apr 1939	1701.8 km	13-16 Mar 1941	2766.7 km
Altitude	Tracy Barnes	USA	Tracy Barnes	USA
	10 May 1964	11780 m	10 May 1964	11780m

	Class A7. 1600 to 2200m^3		Class A8. 2200 to 3000m^3	
Duration	B. Nevernov	USSR	B. Nevernov	USSR
	13-16 Mar 1941	69.20 min	13-16 Mar 1941	69.20 min
Distance	B. Nevernov	USSR	B. Nevernov	USSR
	13-16 Mar 1941	2766.8 km	13-16 Mar 1941	2766.8 km
Altitude	Tracy Barnes	USA	Tracy Barnes	USA
	10 May 1964	11780 m	10 May	11780 m

	Class A9.3000 to 4000 m^3		Class A 10. Greater than 4000m^3	
Duration	B. Nevernov	USSR	H. Kaulen	Germany
	13-16 1941	69.20 min	13-17 Dec 1913	87.00 min
Distance	B. Nevernov	USSR	H. Berliner	GErmany
	13-16 Mar 1941	2766.8 km	8.10 Feb 1914	3052.7 km
Altitude	Tracy Barnes	USA	Cdr. M. Ross USA	
	10 May 1964	11780 m	4 May 1961	34668 m

C_D = drag coefficient
r = balloon radius (m)
v = vertical wind (m/sec)
T = air temperature (°K)

for conditions of a 10-meter ATMOSAT ($C_D = 0.5$, $r = 5m$, $T = 270°K$)

$$\Delta z = \frac{(1.15)(0.5)(270)}{5} v^2 = 31 v^2$$

for modest winds of 1 m/sec, the displacement is only 31 meters and for a violent wind of 5 m/sec the displacement is 775 meters.

2) Effects of rain - Historical experience with rainfall on low altitude balloons shows that the weight of rainfall accumulated on the balloon can be expressed (in kg) as 1/6 of the surface area, or

$$M_r = \frac{S}{6} = \frac{4\pi r^2}{6}$$

For the 10-meter ATMOSAT, this corresponds to

$$M_r = 52 \text{ kg}$$

or 0.3 mm of water on the top hemisphere.

The system at 800 mb has a total weight of 540 kg; the accumulation of 52 kg of rain will add some 10% to its weight, causing a descent of 600 m and a reduction in balloon superpressure of 80 mb.

The 10-meter ATMOSAT is much more stable in vertical wind and rain than the commonly flown zero-pressure gas balloon. Such a balloon, having no reserve of free lift in the form of superpressure, would have to drop ballast if it were caught in a rainstorm, then later have to valve gas to prevent ascent; the ATMOSAT does neither but continues to fly without ballast or gas release.

The accumulation of ice or snow on the balloon is a more significant problem. In such a case, the ATMOSAT would continue to descend to below the freezing level and then allow the ice to melt and be expelled. Flights in inclement weather where the ground temperature is below freezing are to be avoided.

IV. SUMMARY AND LONG TERM PLAN

A. 3.5-METER TESTS

The small ATMOSAT flights will confirm the ability of Sheldahl to properly produce a scale model which can survive launch, ascent, inflation, and long duration exposure to the low stratosphere environment. The thermal analysis to be performed based on flight data will indicate whether changes are needed in the design prior to high altitude flights of larger versions.

B. 10-METER TESTS

The extensive tropospheric test program will collect data on heavy load carrying capability (up to 1/3 ton), thermal response of the envelope, launch techniques and handling, aging, etc., to provide a detailed understanding of the physics of flight of the ATMOSAT. Once this is done the vehicle will be flown on a nonrecoverable flight at 150 mb, with a small thermal monitoring payload for verification of stratospheric performance of that size ATMOSAT.

C. 30-METER DESIGN

Sbusequently, the design effort will move to the 30-meter ATMOSAT size. This vehicle would most likely be equipped with:

1) An internal ballonet allowing full inflation, pressurization, and test on the ground, then launch in a pressurized configuration with air being released from the ballonet during ascent. This would eliminate potential unreliability due to in-flight inflation and pressurization.

2) A pump/valve system allowing the inflation/evacuation of the ballonet in flight to modulate the float altitude as required by the scientific mission.

The design and construction of the 30-meter ATMOSAT, and the initial scientific flight, would be a part of the FY '77 effort to be discussed in later reports.

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